

Practical-Oriented of CNC Educational Tool to Promote Retention of Knowledge for First Year Engineering Students

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Abstract— Computer Numerical Control (CNC) technology has been widely applied in almost small and large-scale manufacturing industries and being extensively educated in universities. However, most of the commercial CNC machines for educational use are only main for laboratory activities and not suitable for teaching use due to its large structures and complicate functionalities. Often, the machines were not designed to serve as an educational tool. This study is restricted to the appropriate CNC education tool was developed as a potential tool that could promote active learning opportunity across multi-discipline of interest mainly for the first year undergraduate students. Besides, its promote retention of knowledge. The article will emphasize on the construction of a CNC tool appropriate to be integrated into teaching computer-aided design that could stimulate student learning. A survey was conducted on student perceptions about the tool for educational use and takes the observational study of the novice student's attitudes in response to a new situation of learning.

Keywords— CNC; educational tool; active learning; computer-aided design.

I. INTRODUCTION

The fast-growing technologies have significant economic decision impact on the traditional manufacturing industries to undergo upgrade replacement to the conventional machines with a new and modern machine to satisfy a new emerging trend of business models nowadays. The Computer Numerical Control (CNC) technology has been widely employed in almost all of the manufacturing industries in the production lines. Such CNC embedded machines are normally operated and controlled through a customized program on a dedicated computer. Apart from the industry sector, education sectors also concerning about validity of existing pedagogies in the manufacturing education and encouraged to develop industry alike framework for final year undergraduate and graduate courses [1].

Nevertheless, the CNC machine for the educational purpose has also equally important as it practically promotes realistic experiences in the manufacturing process and subsequently enhances understanding [2]. A new generation of human capital is indeed essential to affect the gap between demand labor workforce and technological advancements. The new generation of future engineer has to adapt to such technologies changes in the real workplace. A considerable practical knowledge ahead is being essential to the standard first-year engineering students [3] since most

engineering education are practical-oriented education and occasionally develop interrelations to the sub-sequence course of study.

It has been a concern on the trade-off between the level of content difficulty and learning outcome achievable in the context of learning that can be absorbed and achievable to the capability level of novice students (first-year undergraduate student). The ability and speed of learning of novice to quickly follow the new content of learning are associated interactively to their fundamental knowledge, attitudes and learning environment. Appropriate learning environment would have significant influence with mitigating surroundings effect that could quickly settle down attitudes of learning to be more positive and active mindset. The situation for learning is governed by environment setting supported by framework-oriented pedagogy and educational technology. Although technology integration opens the gateway to innovative and quality education [4], it has been a discussion about the level of effectiveness on the available technological tools either it is obtained from the open source or legally. An active learning situation should be conducted proactively in connection to personality and environment that determine the situation of learning. Currently, there has been a great effort to develop a platform for better integration of technologies in the modern education era [5].

Human learning behaviors were somehow associated with the nature of emotions and occasionally react according to emotions as categorized in the arousal-valence (AV) space model and therefore determining the choice of decision and action [6]. The state of behavior could considerably affect the way how someone has taken the initiative according to desire, with appropriate motivational ingredients embedded in learning journey, perhaps could sustain motivation and indirectly influenced learning performance [7]. The engagement and satisfaction are the two main focus of emotions concerned in this research work in the context of learning motivation, and these emotions were classified in the upper-right quadrant of AV space model, are within the active and pleasant state of the learning environment. The main focus is presented in the form of research questions as follows:

- Does active mode in nature of the situation of learning contains passive mode components?
- To what extent the impact of the learning environment influences the attitudes of novice learner?

It has been an issue on student retention [8] particularly from the first year students, and part of the major issue was student engagement in the class. Student experience of active-learning is very much related to the degree of engagement in class. The mobility of Dale's cone of Experience [9] is adapted to a model as indicated in Fig. 1, it can be generally categorized into three major components from the most abstract levels to the more concrete levels.

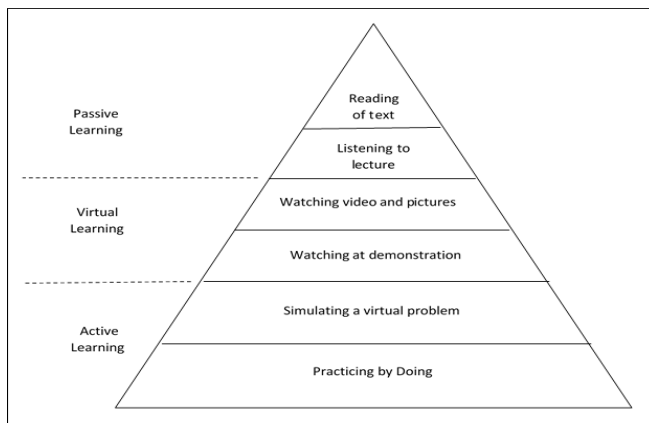


Fig. 1 Model of Dale's Cone of learning

The degree of engagement increased as its go from listening and reading visual literacy, to touching, which hierarchical from a passive mode of learning into more active learning approach. However, the active learning component involves more physical interaction that probably requires also from the abstract method of learning [10]. By selecting the modality from these components so-called hybrid-based approach of learning, we believed that it could increase the degree of engagement and develop retention of knowledge much consolidated.

The CNC education can be generally categorized into two distinct learning environments, that are either real or virtual. The Real learning environment involves the sense of present physically and a situation for experiential learning. Recently, a low-cost desktop CNC prototype machine was reported

[11], but it was constructed mainly only for a significant mechanical engineering course, educating CAD/CAM and CNC machine programming in the laboratory. At Drexel University, the MET316-CNC course focusing on students mastering CAD/CAM, CNC, and automation techniques through capstone project [12]. At King Fahd University of Petroleum and Minerals, a project based comprehensive curriculum has been developed close to the industry related practices on CAD/CAM and CNC machining [13]. At the University of Nis, a CNC machine was implemented for laboratory teaching on various techniques of control [14]. Another inexpensive two-axis CNC lathe was constructed and can be accessed through web-application [15]. Whereas, virtual learning in this context can be appropriately illustrated as computer-based instruction or graphical representation mean for educating knowledge, close to reality and generally as an alternative substitution to the real. At the University of Žilina, they focused on multimedia aided support for learning CNC machine programming [16]. Purdue School of Engineering and Technology concerns on the integration between the virtual reality headset and the aid of mouse and keyboard to create immersive 3D learning experience on the CNC milling machine operation. It is a part of the substitution to the access limitation to the High-end machinery [17]. A similar method also reported but was focused on assist learners' with the hearing problem [18]. In this article [19], they introduced a few crucial stages of 3D virtual training from the machine familiarization, set-up until CNC milling stage. Lastly, the paper [20] concentrated on the use of a simulator that represents the virtual model of the machine, study on numerical control machine behaviors and identify possible collisions before the machining process.

All recent reviewed articles so far were mainly concentrated on enhancing teaching for CAD/CAM and CNC programming and were discipline specific mainly to the significant course for mechanical engineering education. Constructing a portable CNC machine as a potential education tool that can be commonly shared across multi-discipline engineering courses particularly for early-stage engineering education was not emphasized. The use of commercially available CNC machines for engineering education seems not viable to be widely implemented in the university and unadaptable to universal first-year education. It is apparent that the high investment on the expensive CNC machines has restricted the financial ability of the university. Formerly, equipment sharing was achieved by forming groups and provide more laboratory sessions, students typically take turns to access the only one unit of CNC machine installed in the laboratory, and they usually need to accomplish the laboratory exercises within an allocated period. Naturally, restricted the student from obtaining an adequate hands-on experience and valuable learning opportunity when operating the machines in the laboratory.

From the educational perspective, students should not only have understood the control and functioning procedures when operating the machining process, but it will be important also to prepare them with in-depth technical knowledge. Such relevant knowledge should be systematically developed from the beginning course of study. They need to develop a constitution of knowledge accumulated from the elementary level until proficient level

at their major course of study. Occasionally, some CAD-related courses were offered in their chosen programme throughout their study at the university, but they were typically prepared with such assessments to more practical approach only at their major course study. They should have prepared earlier with such learning opportunities and be able to visualize and develop comprehensive knowledge thoroughly until the end of the programme of study. The CNC tool is developed with an initiative to provide the sense of familiarity on the machining process and believed that experience is much grand than of what they could remember.

On the other hand, such a learning environment was challenging to develop from the presence of the commercial CNC machine and usually is structurally sophisticated. Besides, to better prepare students for the challenges industry, they should not be lying only on application ability to accomplish work but to be more technical competency, and avoid too much relying on technological advancement that could change student learning mindset. From the preliminary level of education, the student should also provide an opportunity to explore and learn the basic of cohesive knowledge from design until the production process. They should be prepared and engaged with such a learning opportunity to correlate their knowledge in overall and provide an overview of learning even though only in the first year of their undergraduate study. Such a cohesive arrangement could eventually realize the significance of learning CAD and perhaps appreciate the importance of cohesive knowledge for their subsequence of learning.

Owing to the constraint of the commercial CNC machine that cannot serve the purposes of educating the first-year student to more practical-oriented manner. A small-scale and low-cost CNC machine is known as education tool was constructed and to be used across multi-discipline of interest in educating first-year undergraduate engineering students. In this paper, a small scale CNC tool was constructed with Arduino microcontroller board connected to a computer to execute instructions (G-code) from the computer-aided design (CAD) application software. The Easel [21] web-enabled CAD was proposed to create an online platform for design and provide instructional client interface. Apart from the web-enabled CAD, the Universal G-code sender (UGS) [22] was also proposed as an alternative open source CAD to be used when the machine is operated under offline mode when there is no internet connection. A remote desktop VNC viewer [23] was installed to remotely connect to the workstation at where the CNC machine is placed. A high-resolution webcam was attached to view the workplace of the machine to observe the real-time fabrication through a computer.

II. MATERIALS AND METHODS

A. Teaching Design and Application Software's

A 3D CNC milling tool as shown in Fig. 2 was designed follows the standard structure of the CNC machine with a three-dimensional Cartesian coordinate system with axes in X, Y, and Z directions of motion. Due to the mobility concern, a small scale CNC tool was proposed with an overall structural size of about 300mm (length) x 300mm (width) x 410mm (height) and with allowable maximum

workpiece size of 120mm x 115mm. The axes mechanisms for tool positioning are driven by three units of stepper motors controlled by it drivers and connected to a control module using a low-cost Arduino microcontroller board; the milling is achieved with an electric grinder installed on the z-axis. For the CAD software, an Easel CAD as shown in Fig. 3 was proposed mainly is because the software is free, user-friendly, suitable for beginner and a web application software that provide a one-stop solution yet sophisticated enough for first-year entry student to develop prerequisite knowledge from the design to fabrication stages.

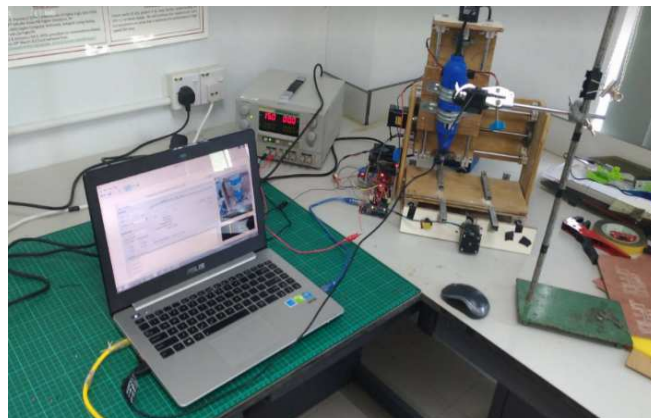


Fig. 2 An overview of the CNC education tool

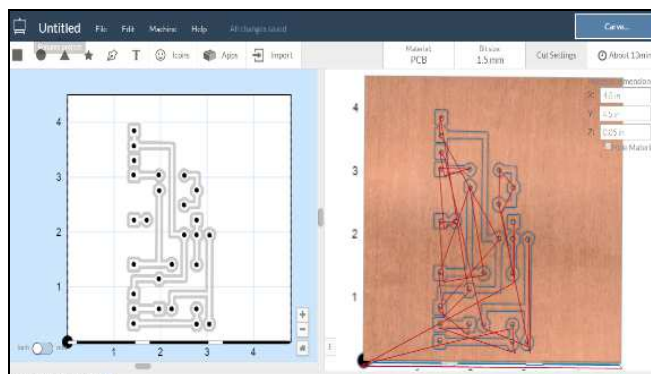


Fig. 3 Easel CAD

Unlike conventional milling method which required to use the sophisticated and dedicated computer-aided design and manufacturing separately to accomplish similar tasks. Alternatively, the universal G-code sender (UGS) can also be used for offline mode operation, similar to the Easel, the UGS as shown in Fig. 4 also allows to visualize the real-time movement of the fabricating route on the current position of the bit movement simultaneously. A student can also upload G-code retrieved from the Easel to run similar operational task through the UGS, and specific command lines can be manually inserted to observe the desired movement or study of G-code programming. Both CADs were comparable to the commercial product that can serve similar learning outcome at the elementary level course of study. A high-resolution webcam was installed and positioned explicitly at the workspace area for real-time viewing from a remote location through the VNC viewer. Through the software, the CNC tool can be similarly controlled from a remote computer or smartphone.

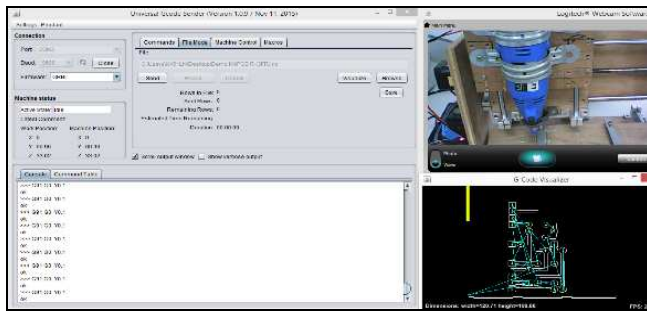


Fig. 4 UGS CAD

From the preliminary trial, the CNC tool was operated as expected on the accuracy of the milling process on two different materials as demonstrated in Fig. 5. It also indicated that the tool could be used across two different academic disciplines. A student from Electronic and Electrical Engineering field used the tool to fabricate PCB whereas student of Mechanical Engineering field can mill plywood, metal, plastic, aluminum materials, etc. with a selected bit types. For the PCB fabrication, the conductive paths of the circuit layout were considered fabricated successfully, and the holes for components placement were completely drilled through. The milling on the plywood was also begun fabricated according to the drawing.

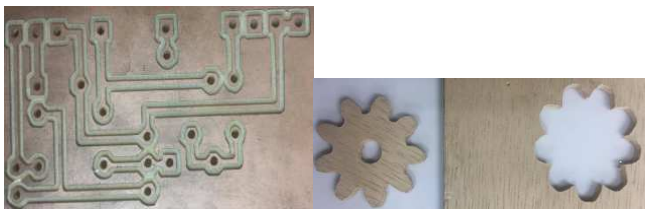


Fig. 5 PCB fabrication (left) and cut through plywood (right)

B. Commercial CNC Machine versus CNC Education Tool

The commercial three-axis CNC milling machine/lathe (Denford-VMC 1300) installed at the Swinburne University of Technology in the mechanical laboratory is approximately five times larger than the CNC tool as shown in Fig. 6 and consider not suitable to be used for classroom demonstration or teaching use. It was customized either physically or functionality and restricted the ability to reconfigure for multi-disciplinary use. Whereas, the CNC tool can be operated or controlled in almost other free CAD software compatible for materials milling, engraving, lathing, routing, etc. Besides, the cost of the CNC machine was estimated around RM100,000 when compared to CNC tool which only incurred a fraction of cost of around RM900. Moreover, the CNC tool is much power-saving required only 15V to operate.



Fig. 6 CNC education tool (left) and commercial CNC machine (right)

In conjunction with the education tool being constructed, we have decided to apply a practical-based pedagogical approach to promote retention of knowledge that could support further development of knowledge and contribute towards the subsequence of higher learning and a more complex level of learning. Most probably the approach can allow engineering students are associating basic of the interrelationship between CAD and CNC production process as a whole. One of the challenges of teaching lab related course to engineer students is to prepare and distribute relevant practical knowledge at the level necessary to be obtained in line with the current trend of practices in the industry, not only until their proficient level but also most importantly educating them started from the beginning of the programme of study. At the university, the Engineering Drawing is part of the syllabus in some first-year engineering courses and was included in the CVE10002 Professional Engineering, RME10001 Robotics & Mechatronics project 1 and TNE10003 Professional Skills – Electrical Engineering courses. Part of the present developed learning activities for the CVE10002, and RME10001 courses were consider conducted traditionally that teaching computer-aided engineering drawing based on the existing instructional materials and placed students in a passive role. Normally, most of the first year students especially newly enrolled students do not mature in their mentality with non-dedicated aim and ensure future direction, such cohesive knowledge arrangement could gain an overview of their subsequence learning and consistently develop means of learning. For TNE10003 course, the student obtains printed circuit board (PCB) generated from the schematic but apply a conventional approach that has long time absolute from industry practices, however, this approach is well-known method particularly for hobbyists, but industry nowadays has gone so far more than advance. Such observations developed an initiative for the development of the CNC education tool, and it was introduced and incorporated in the courses with a new basic drawing platform that comprises of prototyping process features. Conventionally, such a prototyping process is typically accomplished by its distinct components in the process that includes CAD/CAM/CNC programming which is usually found in a more specialized mechanical engineering course. With such integration, its structured a new and more interactive learning environment to the student. We believed that with such influence, the student can gain an appreciation to the sense of more industry alike, develop their desire and willingness to learn and to be more actively engage as a role of learner.

On the development of the computer lab related learning instrument according to their discipline of interest specifically in line with the continuous quality improvement exercise. It should be prepared and aligned with the intended unit learning outcome (ULOs) of the courses/unit as listed below:

- 1) Part of the ULO relevant to CVE10002 Professional Engineering course:
 - Generate professional CAD drawings for simple engineering objects.
 - Apply engineering methods in any particular engineering project.

- Discuss professional engineering careers and emerging trends in Civil/chemical engineering.
- 2) Part of the ULO relevant to RME10001 Robotic and Mechatronics course:
- Analyze and design structured computer programs for solving moderately complicated algorithms.
 - Apply computer programming practices to solve real problems.
 - Use CAD software to the level listed by AS1100 Engineering Standards and Conventions.
 - Interpret technical drawings.
 - Demonstrate graphical communications skills.
- 3) Part of the ULO relevant to TNE10003 Professional Skills –Electrical Engineering course:
- Maths and IT as Tools: Proficiently usage of relevant mathematics and computer and information science concepts as tools in complex engineering activities.
 - Design: Systematically uses engineering methods in designing solutions to complex engineering problems.
 - Engineering Methods: Applies engineering methods in practical applications and complex engineering problems.

III. RESULTS AND DISCUSSIONS

Some surveys were conducted to some groups of undergraduate students at the University. A survey by questionnaire was being prepared and conducted in the laboratories to collect feedback from students who have recently undertaken the courses. The first survey was taken on Professional Skills-Electrical Engineering course (TNE10003). A total number of 45 students participated in the survey on operating the CNC education tool in the laboratory with assistance. The survey was prepared to collect student perceptions on the tool used for engineering education. The questionnaire was created in the Google forms to collect students' feedback, and their survey response is further explained in the following sections.

From the first year student point of views, among the 51.1% indicated that more than half of the students were unaware of the presence of CNC milling machine, the machine was rarely used in the university most probably because of the lack of exposure in their context of learning. Students who have participated in the survey agreed that technology plays a significant role in education and the majority agreed that practical experience is essential for their future career. With greater than 75% of students agreed that the CNC education tool could promote better understanding in their relevant course of study. Besides, among 75% of the students desired that more than the regular learning opportunity can be developed instead with the aid of the CNC tool as part of the learning support. Almost all the students preferred real experience when they were giving options. They express acceptance to use the tool to support their learning and looking forward to seeing the development

of the machine for educational use in the future. A total of 73.3% of students believed that the CNC education tool implemented in the course could achieve improvement in the teaching and learning outcomes. Generally, the students expressed their supportive comments and only less than 10% of the students rated with unsatisfactory opinions. Lastly, some of the students suggested to further reduce the physical size, noise and more power-saving of the CNC tool.

The second survey was taken one semester later on both the Professional Engineering (CVE10002) and Robotics & Mechatronics Project 1 (RME10001) courses. A total number of 67 students participated in the survey. The survey was conducted with a 10 minutes short lesson for 2-4 students per group. The lesson was conducted a week later after all CAD topics were delivered at almost the end of the semester. Majority of student agreed that the short lesson conducted was applicable and meaningful to the subject. Most students were working in a group with a minimum of 2 to a maximum of 4 students. 55.2% of the students do not find the short lesson difficult at their level of understanding. However, the remaining 44.8% of them found that it was difficult, the possible reason for such disagreement could be due to that was an entirely new experience to them as a first-year student. However such supportive experience could be meaningful for the subsequence level of their learning journey. A short duration of 10 minutes' lesson is considering acceptable by most students. 35.8% of the students argued that the lesson was conducted a bit rushed. More teaching tool can be constructed if some students are growing so that a longer lesson can be arranged. 62.1% of the students had expressed unconfidently that they might be able to recall what they have been experienced after three years. Among the students that were confidently expressed, 2/3 of the students would be able to recall on such tried experience. From the observation, nearly half among the students required to follows the instruction manual on the procedures to be able to handle the tool again after the first try. More than 80% of the students have received some practical knowledge's and understood the correlation between CAD and CNC machining process. The feedback has received more than 90% of the subjective comments on the importance of learning CAD after they have been inspired with the short lesson and they are interested in exploring a deeper understanding on the machine operation and process in near future. 53.7% of the students expecting that they might involve working with such machine process after graduate.

IV. CONCLUSION

A CNC education tool was developed with the aim to promote student engagement in the first year engineering education across several filed of interest in the university. A low cost and small scale CNC tool suitable for educational use were designed and constructed from an Arduino board connected to three stepper motors for X, Y and Z motions controlled directly from CAD software. The high installation and maintenance cost can be greatly neglected with such tool being implemented. The CNC machine can be used for teaching improvement and support student learning. With the aid of VNC viewer, it allows remote access to the CNC machine, at where the CNC tool can be remotely controlled

using a computer or smartphones with real-time viewing. Both CADs were comparable to the commercial product that can serve similar learning outcome for the elementary level course of study, and various types of raw materials were fabricated using the CNC tool. The tool was operated, and able to produce desired processing from the design as expected. From the students' perception, we received supportive comments to further implement the CNC tool for teaching use.

This research work received the positive side of nature on the responses from the students' perspective when they have been diverted from a passive to an active mode environment that placed the student in a new situation of learning. Students have seen and experienced upfront on the future outcome of learning from this specific guarded and guided activities. The implication of the observation study shown that it has great significant impact relationship between attitudes and learning environment towards knowledge.

For future work, we will take the study of Kolb's four learning styles [24], [25] for the early stage of engineering education in this context and its implication. From the hardware perspective, the electric grinder can be replaced with small size yet powerful. The tool could be meaningful if the overall structure of the CNC milling tool can be further minimized while maintaining the work piece size. Also, the automatic drill bit changing mechanism can be implemented if remote teaching and safety are concerning. Last but not least, a vacuum system can be added to provide a clean learning environment.

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